GENERAL PHYSIOLOGY
OF
THE NERVOUS SYSTEM:

A LECTURE

DELIVERED IN

THE CITY HALL, GLASGOW,

UNDER THE AUSPICES OF

The Glasgow Science Lectures Association.

BY

JOHN GRAY M'KENDRICK, M.D.,
F.R.S.E., F.R.C.P.E.,
PROFESSOR OF THE INSTITUTES OF MEDICINE IN THE UNIVERSITY OF GLASGOW.

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GENERAL PHYSIOLOGY OF THE NERVOUS SYSTEM.

Last year you will remember that Dr. Allen Thomson delivered a lecture in this hall upon what he very properly called the architecture of the brain and of the nervous system. The lecture which I propose to deliver this evening may be regarded as a continuation of the lecture given by Dr. Allen Thomson. You will recollect that in that lecture he pointed out to us that the nervous system consists, in the first place, of certain cords found in almost every part of the body called *nerves,* and of certain masses of matter found in other parts of the body, to which he gave the name of *nerve centres.* These nerve centres, you will recollect, he classified as *ganglia,* or smaller masses of nervous matter found in certain parts, and the *brain* and *spinal cord* constituting what he termed the cerebro-spinal system. You will remember also how he showed us that the nervous system, when traced from the simplest forms in the lower animals to its more complete state in the higher animals, gradually becomes more and more complex from the development of new parts. He illustrated this by taking us through the different groups of the vertebrate kingdom of nature, and showed us how, from the simple brain, as found in the fish, we might pass step by step, to the brain of the reptile, of the bird, up to the brain of the mammal; and at last he described the architecture of the brain of man, which is the most complex of all. He illustrated the same general principle of evolution, from the simpler to the more complex forms, by tracing the development of the brain in a single individual, from its earliest form in the embryonic state to its full completion in the adult. In order to refresh your memories in regard to one or two of these points, so that you may be better able to comprehend what I have to say regarding another aspect of the subject, I may direct your attention, in the first place, to one or two of the diagrams which Dr. Thomson showed us on that occasion. This large diagram represents a side view of the brain of man. Underneath, we have a diagrammatic or typical brain; and I wish you to keep in mind that it consists essentially of the following parts:—First, of a large mass (bounded by dotted lines, in the lower diagram), representing the *cerebrum* in a fully-developed brain. Behind this, and overlapped by it, in the higher brain, we have a mass of nervous matter called the *corpus striatum.* Behind this, again, a somewhat smaller mass, to which the name of *thalamus opticus* has been given—an old name given by anatomists, who thought that this part of the brain was more specially connected with the sense of vision. Behind the *optic thalamus,* we have a still smaller mass of matter, which we shall call the *optic lobe,* specially connected with the nerves of vision. Behind this, again, we have a continuation of the brain in the form of *crura,* or *peduncles.* Then the upper part of the spinal cord or marrow called the *medulla oblongata.* Lastly, we find the spinal cord itself. These are the parts, the names and general position of which it will be important to carry in your memory, so as to understand what may be hereafter said as to their uses.*

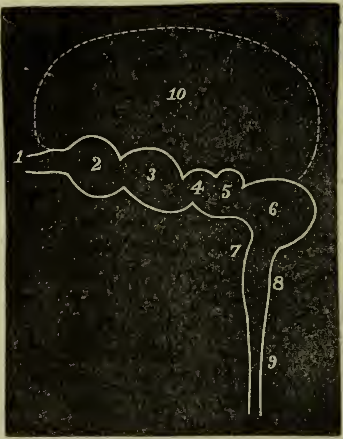

Fig. 1.—Diagram of an Ideal or Typical Brain. 1, Olfactory lobe; 2, cerebrum; 3, corpus striatum; 4, optic thalmus; 5, optic lobe; 6, cerebellum; 7, pons Varolii; 8, medulla oblongata; 9, spinal cord; the dotted curve indicates the possible development of the cerebral lobes.

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* The woodcut here introduced, although not a copy of the diagram actually shown at the lecture, illustrates this paragraph.

Let me direct your attention to several other diagrams constructed by Dr. Allen Thomson. This diagram gives us a general view of brain-development, from the brain of fish upwards to the fully-developed brain of man. This other diagram gives a general notion of the arrangement of the spinal marrow or spinal cord. You will see that the cord consists of a series of columns of white matter, placed side by side, and enclosing a mass of grey matter in the centre. From the sides of the spinal cord, and from the base of the brain, we have numerous nerves originating, which course or run through various parts of the body. These are the principal anatomical points which I think you should remember in order to follow the physiological side of the question.

This evening, I now ask you to look at the nervous system, not from the anatomical side, nor from the point of view of the comparative anatomist, but from that of a physiologist. The science of physiology has for its object the investigation of the *functions* of organs. The science of anatomy, of course, has, strictly speaking, to do with the *structure* and *form* of organs, and also, I think, with the *evolution* of organs, as traced throughout the animal kingdom. When we examine the different forms of animal life, we first of all notice that in the lower orders there is no trace of a nervous system. There are many microscopical organisms, and many organisms quite visible to the naked eye, which have no nervous system. And yet, if we stimulate or touch these organisms, we may cause them to move. One of the first and most remarkable phenomena of life with which we have to do is *movement.* Many minute and almost structureless animals move by contracting—by changing their form—and this they may accomplish without any nervous system whatsoever. As we proceed higher in the scale, we come to animals where a nervous system begins to be apparent. It has been generally supposed that the nervous system first made its appearance in the form of little masses of nervous matter connected with two nerves. Quite recently, a number of most important observations have been made upon *medusæ* by Mr. Romanes, who has paid a great deal of attention to these interesting animals. You are all familiar with the forms of the beautiful medusæ we see floating in the sea. These creatures are sometimes clear and transparent as glass. They move by rhythmic contractions and expansions of certain parts of the body. Mr. Romanes found that they might be experimented upon, and that they moved or made rhythmical contractions when stimulated at certain points. He discovered that, if you touch one of these medusæ, or irritate it, say by an electric current, a sort of wave will be transmitted from the point irritated towards the centre of the animal's body, or perhaps to some particular part of it. He also found that if he took a large medusa, such as we find in the Moray Frith, and cut it into the form of a long ribbon, and irritated one end of the ribbon, a movement or wave of contraction passed to the other end. He observed that if he cut the ribbon half-way across, cutting from each side of the ribbon, as it were, so as to leave simply little strips connecting its segments, that still, on irritating one end of the ribbon, the movement passed from the point of irritation towards the other end. All this indicated what might be regarded as a beginning or differentiation of a nervous system, in the sense that there were definite paths along which the stimulus might travel. More recently, as I have been informed by letter, Mr. Schäfer, of University College, London, has been investigating the structure of some of these medusæ on which Mr. Romanes experimented, and he has found indications of a nervous tissue. Thus, in these simple creatures, whilst there are no nerves, there are what may be called "lines of nervous force" —lines along which a special influence passes which results in contraction. These lines of tissue, in higher forms of life, may gradually become more differentiated into what we ultimately term nerves.

The next step we notice is when we have to do with *nerves*, *ganglia*, and *centres*. What is the structure of a *nerve?* A nerve, when seen with the naked eye, presents the appearance of a white cord. When examined under the microscope, it is found to consist of an immense number of fibres. These little fibres, when seen individually under the microscope, are clear and transparent like glass, but when looked at attentively, they are found to have definite parts.

This figure represents a view of a nerve fibre diagrammatically. It consists of a delicate sheath outside, within which there is a cylinder of matter — which we call the *white substance*, but which in the diagram I have coloured blue, simply for the purposes of illustration. In the centre of the white substance, we have semi-gelatinous material (coloured red in the diagram), which we may term the *axis rod*, or *axis cylinder*. Suppose we make a section of a single *nerve fibre*, what is here represented in blue, is the white substance, surrounding the axis or cylinder rod. A nerve is made up of an immense number of these little nerve fibres laid side by side.

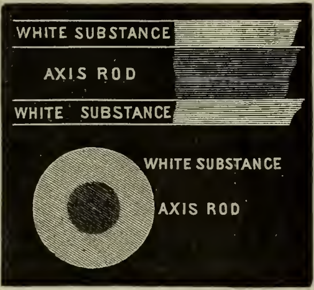

Fig. 2. — Diagrammatic View of the Structure of a Nerve Fibre. Above, longitudinal; and below, transverse section.

This diagram represents a portion of a section of the optic nerve of a horse. The nerve was hardened, and a thin transverse section made of it, which was stained with colouring matters employed in histological work. We see a portion coloured red, which consists of a kind of connective tissue binding the whole together. Then you have enormous numbers of nerve fibres. In this section

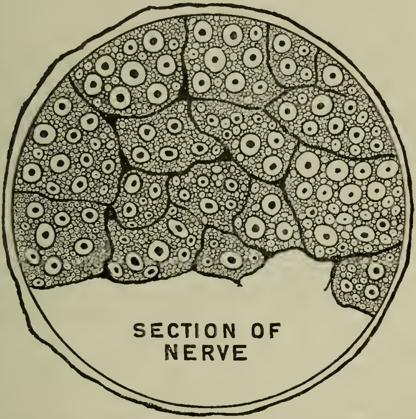

Fig. 3.—Transverse Section of a Nerve, showing the Bands of Connective Tissue and Sections of Nerve Fibres.

you see them cut across. The axis rod is represented as a dot; and in the section of the nerve you have the nerve fibres of different diameters, some of them being very much greater than others. That, then, is the general structure of a nerve.

Now, let us ask ourselves next what is the function of a nerve? Perhaps the best way we can illustrate that is to imagine that we can submit it to some kind of experiment. We cannot learn anything of its functions by simply looking at it. We might learn something about it by tracing it, and finding out where it goes. If we found it went to a muscle, we would naturally conclude that it had something to do with muscle; if it went to a blood vessel, we would conclude it had something to do with blood vessels; or if it went to the brain, we would conclude it had something to do with the activities of the brain. Suppose we irritated it in some way, say by a feeble electrical current, various things might happen which would indicate what its functions may be. In the first place, we might have a *contraction of the muscle*—the muscle supplied by the nerve. When the nerve is irritated, this muscle might contract. The various movements of locomotion and other voluntary movements are carried on in this way. When we lift the arm, a nervous impulse travels along certain nerves from the brain or cord to the muscle, the result being a muscular contraction. But, instead of muscular contraction, we might have possibly *secretion from glands.* Thus there are nerves which supply the salivary glands; and if we irritate any of these nerves, there may be an increased secretion of saliva. Among the many nerves in the body, there can be no doubt at all that there are certain ones which excite secretion. But, again, instead of movement—or contraction of the muscles—or secretion of glands, we might have a change produced upon the *diameter* of *blood vessels.* The little blood vessels which ramify through the body, carrying their supply to the organs and tissues, are not tubes of the same calibre at all times; but they are tubes having contractile walls, and these walls are also under the influence of nerves. On irritating some nerves, we might see the calibre of the vessel becoming much narrower; while, on irritating other nerves, possibly the calibre of the vessel might become much larger. We thus might have, on irritating a nerve, contraction of muscles, secretion from glands, or possibly a change in the diameter of vessels. Then, fourthly, on irritating the nerve, there might be indications of feeling. In that case, the nerve must have passed, in some way or other, to a sentient brain. Nerves then carry impressions from the periphery of the body to the centres, and when they reach the sentient centres (of which I shall have to speak presently), the result is a sensation or feeling.

These are four modes of nervous activity, which we may notice in almost any animal, and which occur in man. In some animals, however, nerves supply other structures. For example, here is a diagram in which you see represented a peculiar fish, the torpedo, an inhabitant of the Mediterranean. This fish belongs, as many of you know, to the family of the Rays or Skates. Its general formation and appearance are shown by the diagram. You will observe that we have laid bare the nervous system and ganglia of which I have been speaking. You will see numerous nerve cords passing from the nerve centre and distributing themselves to very remarkable looking organs shaped somewhat like a honeycomb. These are electrical organs. If you touch this creature, placing one hand on the back of the fish and the other on the belly, you get a severe

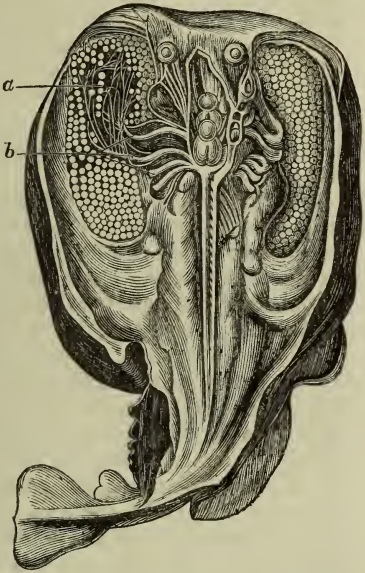

Fig. 4.—TORPEDO, showing the Brain, Spinal Cord, and Nerves; also the Electric Organ supplied by large Nerves, *a*. The Electric Organ is the honey-comb like structure, *b*.

electric shock. It is interesting to know that the discharge of electricity from this electric organ depends upon the activity of the nervous system. When the electric organ is examined closely, it is found to present a very close analogy to the structure of the voltaic pile; that is to say, if you take different metals, separate them by little bits of some bibulous materials, and immerse the whole in some solution which will act on one of the metals, you obtain a current of electricity. In the torpedo, each of these little hexagonal bodies may be regarded as a little pile similar to a voltaic pile. It has been ascertained by careful experiment that the nerve is distributed to the *positive* surface of this pile. The interesting point in connection with the physiology of the torpedo is, that in it nerve action may produce changes in tissue which result in a discharge of electricity. We have thus an *electrical phenomenon* dependent on nervous influence.

Consequently, to recapitulate, a nerve, on being stimulated, may produce motion or contraction of the muscles, or it may produce sensation or a feeling of pain; it may produce change in the calibre of the blood vessels, secretion from the glands, or, possibly, some electrical discharge from a special electrical apparatus, as in the case of the torpedo.

In the next place, suppose you proceeded to examine the nerves going to the different parts of the body. The first thing that would occur to you is, that you would see no visible difference in the nerves; they present the same appearance (except in size), so that you could not tell one from the other, although stimulation of them may produce such diverse effects. Nor can you make out any distinctions even with powerful microscopes, as all the nerve fibres look alike. This leads us to the important inference that the different effects produced by stimulating different nerves does not depend on the structure of the nerve, but upon the nature of some apparatus at its end. The nerve is then really a *conductor*. When stimulated, it displays a mode of activity which we may term nerve force or nerve energy; this travels towards a termination, and the effect produced depends upon what we may call a *terminal organ*, or the apparatus at the end of the nerve. You will understand this perhaps by taking an analogy from electrical phenomena. A copper wire conducts a current of electricity, and this current may be caused to do very different kinds of work. For instance, the current might be employed to do mechanical work by driving a little electro-magnetic engine; it might also be used for producing chemical decomposition, as in electrotyping; or it might be used for producing the phenomena of light, as in the electric light; or it might, by altering the condition of a small magnet, cause a little disc to vibrate, and thus produce sound, as in the telephone. You will observe that the copper wire will conduct the current to any of these different kinds of apparatus, but the difference of effect really depends upon the apparatus at the end of the wire. Now it is similar in the case of the nerve. The nerve, as I have said, may be regarded really as a conductor—a conductor of some change or other in the nerve—and the effect produced depends upon the nature of the apparatus at the end. If the apparatus be a cell or cells in a sentient brain, the result will be a feeling of pain, or perhaps of pleasure. If the nerve terminate in an electrical organ, it will be an electrical discharge; if it end in a muscle, it will be a muscular movement or contraction. This important generalization has been the result, as you will quite understand, of a great deal of physiological investigation. At one time it was supposed that the different nerves had different properties, and that what was called a *motor* nerve, or one which causes motion, was different in structure from a *sensory* nerve, which, on being irritated, might cause a feeling of pain. We now know that that is not the case. The nerves are similar, but the effect depends upon what is at the end.

The nerve, you will observe, is thus a conductor; but at the same time it is something more than a conductor. Suppose you were to expose a nerve in any part of its course, and irritate this nerve in any way at that point, at once you set up some kind of activity in that nerve which travels along the nerve. Consequently, a nerve is not only a conductor, but it is an *excitable* conductor — it is capable of being excited by an external stimulus, applied at any point. In this respect, you will see that it differs from an electrical conductor. It is capable of being touched or stimulated or irritated at any part of its course. Many of you must no doubt have been struck with the remarkable analogies between nervous action and electrical action. The very appearance of a transverse section of a nerve (see fig. 3) suggests the idea of a cable having a number of wires for the conveyance of currents of electricity; and if you can imagine this cable branching off here and there to go to different towns or places, you have at once something remarkably similar to a nervous distribution. But you may make the analogy even more close. If you look at the transverse section of a single nerve fibre, it suggests to one some kind of an insulated structure. When the electrician wishes to keep the wires from contact, so as to prevent the passage of currents from one wire to another, he covers the wire with some non-conducting substance. Now, when you look at a nerve fibre, you see an axis-rod surrounded by the white substance. We have no proof that this white substance is really an insulator; in fact, it is not an insulator of electric currents, at all events—and we have no absolute proof that it is an insulator of the energy which passes along the central rod. But you say, what reason have we for supposing that the central rod is a conducting structure? This view is founded principally upon histological evidence, that is, the evidence got by microscopical examination. If we trace a nerve fibre to its termination, we find it ultimately terminates by the central rod connecting itself with the terminal apparatus. For example, if you trace a nerve into the spinal cord, we find that it may end in what is termed the pole of a nerve cell in the grey matter of the cord. You find that the central rod comes into absolute organic contact with these cells. The white substance disappears before the central rod comes into contact. Again, if you trace nerve fibres into connection with the terminal apparatus in the eye—the retina—or with the terminal apparatus of the ear, by which we appreciate sound, you find illustrations of the same truth—that the central rod is what is connected with the terminal organ. Consequently, the central rod is, in all probability, the conducting structure.

There are many points of difference between what we may call electrical conduction—or conduction of electricity along a conductor—and nervous action. One of the most remarkable facts is that the nerve current passes along a nerve with comparative slowness. It does not travel at anything like the rate of electricity, for instance, along a copper wire (288,000 miles per second—*Wheatstone*).

One of the triumphs of modern physiology has been the measurement of the rapidity of the nerve current. If you move the finger, the movement, you think, is instantaneous. If you *will* to move a finger, the finger is apparently moved the instant you will that the thing is to be done. No time seems to be lost. This results from the fact that our appreciation of minute intervals of time does not pass beyond a certain limit. We cannot appreciate very minute intervals of time. We cannot observe a period of time of less, say, than one-tenth of a second. If two phenomena happen, separated by a shorter interval than the one-tenth of a second, they seem as one to our consciousness. Many phenomena, however, may occur, and do occur, in a much less space of time than that. I have had a diagram constructed to show how physiologists have measured the rate of a nerve current. There are many experiments which cannot be done in such a hall as this, and therefore we shall have to be contented with what we see in the diagram. Take the muscle of a frog having a nerve attached to it. We stimulate this nerve, laying it across two wires, A and B. The problem is to find out how long the nerve current takes to pass from A to B., etc., in fig. 5. The velocity of the nerve current in a *motor* nerve was first determined by Professor Helmholtz, of Berlin.

Various modes of measurement have been adopted by physiologists from time to time, but the general principle of all the methods is to cause a muscle to contract by successively irritating two points of a nerve more or less distant from it, and to obtain a record of the contracting muscle upon a rapidly moving surface. It is evident that the distance between the two points at which the two curves leave the horizontal line will indicate the length of time the nerve current took in passing from the stimulated point, at a distance from the muscle, to the other stimulated point close to the muscle. A convenient arrangement for making the experiment is shown in this diagram (fig. 5), in which an instrument termed the spring-myograph of Du Bois-Reymond is employed.

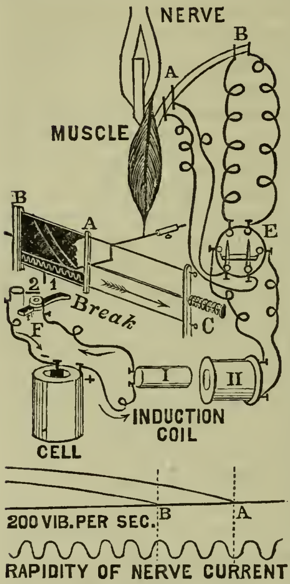

Fig. 5.—Diagram showing arrangement of Apparatus in experiment for measuring the rate of the Nerve-current.

The apparatus consists of a smoked glass plate, which is driven in front of the recording stylet of the myograph by the recoil of a steel spring C. Underneath the frame carrying the glass plate, there are two binding screws, 1, 2, to one of which is attached a rectangular arm of brass, 1, which can so move horizontally as to establish metallic connection between the two binding screws (marked *break* F in the diagram). By means of these binding screws, the myograph is interposed in the circuit of a galvanic cell, and the primary coil (I) of an induction machine, and the arm of brass is so placed as to connect both binding screws, and thus complete the circuit. From underneath the frame carrying the smoked glass plate there descends a small flange which (when the glass plate, by releasing a catch not seen in the figure, is driven across by the spring or spiral at C from left to right) pushes the brass arm aside, and thus interrupts the circuit of the primary coil. When this occurs, an opening shock is transmitted from the secondary coil, II, to a commutator, E, an instrument by which electric currents may be transmitted in one direction or another at pleasure. By means of the commutator, the secondary shock may be transmitted to the nerve, either to a point close to the muscle at A, or at a distance from it at B. Suppose the apparatus all arranged, so as to send the shock to the nerve at a point close to the muscle, A, the muscle thus stimulated contracts, and draws, by the stylet, on the smoked surface of the glass, the curve A, seen in the lower part of the figure. This curve leaves the horizontal line (which would be drawn by the muscle at rest) at A. Arrangements are then made for another experiment, in which the nerve will be stimulated at a distance from the muscle, at the point B, in the upper part of the diagram. This is done by again placing the smoked glass plate in proper position, closing the primary circuit by the brass arm at the binding screws, as already described, and reversing the commutator so as to send the shock along the wires to B. The muscle again contracts when the primary circuit is opened, and this time it describes on the smoked surface the curve B, seen in the lower part of the diagram. It will be seen that this curve leaves the horizontal line at B, that is, a little *later* than when the nerve was stimulated close to the muscle. It follows, therefore, that the distance on the horizontal line from A to B represents the time occupied by the transmission of the nervous impulse from B to A of the nerve. With suitable arrangements, the rate of movement of the glass plate can be measured, by bringing a vibrating tuning fork into contact with it. The vibrations of the fork being uniform as regards time, the little waves thus recorded enable us to measure with accuracy the rate of movement of the glass plate, and consequently the minute interval of time between A and B. In the diagram, it will be observed that there are two waves between A and B; each represents $\frac{1}{200}$ of a second, and $\frac{2}{200}$ of a second, or $\frac{1}{100}$, is the time represented by the length of the line from A to B.

When this experiment is carefully done, it is made out that, in the frog, the nerve current travels at the rate of about 90 feet per second. That is comparatively a slow speed. By other methods, which I have not time to describe, the rate of the nerve current can be measured in the living man without any great trouble; and it has been found that in man, and probably in other warm-blooded animals, the current goes at the rate of about 200 feet per second. I need not say that that is incomparably slower than the passage of a current of electricity along a wire (see p. 13).

The next point I wish to direct your attention to is, what is it that really passes along the nerve? That is an extremely difficult question to answer. In fact, at this moment it cannot be answered satisfactorily. It is not electricity, in the sense that it is often spoken of. It has been supposed by some to be a kind of molecular movement passing along the nerve. Some have supposed that it was an instantaneous chemical change produced at the point of irritation, and that this chemical change was transmitted very quickly from point to point along the nerve. From various observations which I have made, I am inclined to think that, when a nerve is irritated, a change passes simultaneously to both ends of the nerve. Formerly, we were in the habit of supposing that, when we irritated a nerve at one point, the current went only in one direction. But there are a number of facts to show that, when we irritate a nerve at any particular point, the change goes in both directions. You say, How is it, then, you have not an effect in both directions? The answer is, because it will depend on the nature of the apparatus at the end of the nerve. When we irritate a nerve, as I said before, an effect will be seen only at the end at which there is a responsive terminal apparatus. No apparent effect will be observed at the other end, but there may be transmission in that direction notwithstanding. Imagine a long india-rubber tube filled with water lying on the table, and that at one end of it there is a little lever laid across it. On tapping the tube smartly in the middle, a wave will be propelled towards *each* end of the tube, but its existence will be shown only at *one* end by the movement of the lever. So is it, I think, with a nerve. Irritate a nerve in any part of its course; from its structure, and from various experiments, I infer that an impulse travels to both ends, but direct evidence of this impulse will be given only at the end in contact with a terminal organ.

Next, what occurs at the termination of the nerve? That we may illustrate very well by taking the example of muscular contraction. Here we have a muscle fixed in a little apparatus, and a nerve stretched across two wires. We have attached the muscle to a long lever, which you see; and when we irritate the muscle, you see the lever lifted up; and if you have a weight attached to this lever, you cause the muscle to do work in lifting the lever, and in lifting a certain weight. An extremely feeble current is quite sufficient to irritate a nerve, and consequently the amount of work which a muscle does in lifting a weight does not depend on the amount of stimulus which you apply to the nerve. You set the nerve in action, and it conveys some kind of stimulus to the muscle, which has the result of liberating the energy stored up in the latter. The muscle may be regarded really as containing energy in a potential condition, and the action of the nerve is not merely to force the muscle to contract; but, as it were, to set free this energy in the muscle. The change is manifested by a contraction. The relation of the nerve to the muscle is something similar, for example, to the relation of the trigger that acts upon the percussion cap, and explodes a great mass of gunpowder. The gunpowder contains, of course, an immense amount of energy which is locked up or latent. You liberate this energy by setting up some kind of action by means of the percussion cap, and instantly the liberated energy will do work. In the same way, in nervous actions, a very feeble primary irritation is sufficient to produce a great effect. The muscles contain energy stored up in themselves, and the nerve may be regarded as the liberator of the energy. In like manner, the brain and nervous centres generally may be regarded as stores of energy which we have obtained from food, and the action of the nerves is to set up changes in these parts, so that energy is set free. The energy thus set free may be manifested in various ways, as we have seen.

We next pass on to consider the *nerve centres.* These are made up of nerve cells and nerve fibres. I have already said enough about nerve fibres. Nerve cells are of many kinds. They are microscopic in size, and they present many varied forms. I exhibit one of Dr. Allen Thomson's diagrams, and you see a vertical section of the grey matter on the surface of the brain. In this matter, observe the peculiarly formed nerve cells. Each of these nerve cells has minute processes or poles proceeding from it, and each pole is connected either with a similar pole from another nerve cell, or with the axis cylinder of a nerve. You can trace, as I have said before, the axis-rod into connection with these cells. You see in this diagram two or three very large cells of quite a different form, such as you might obtain from the grey matter in the centre of the spinal cord of an ox or any large animal. A single nerve cell, with two poles or processes, may be regarded as the simplest kind of nerve centre.

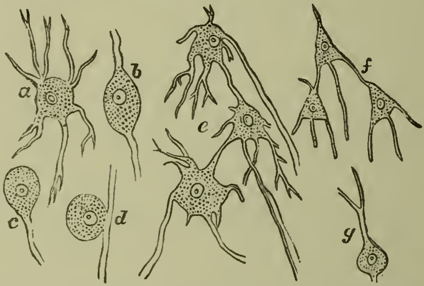

Fig. 6.—Various Kinds of Nerve Cells. *a*, *Multipolar*, from grey matter of the spinal cord; *b*, *d*, *bipolar*, from ganglion on posterior roots of spinal nerves; *c*, *g*, *unipolar*, from cerebellum; *g* shows indications of a process coming off at lower end; *e*, union of three multipolar cells in spinal cord; *f*, union of three *tripolar* cells in grey matter of cerebral hemispheres.

In discussing the physiology of the centres, I wish to proceed according to the same plan as Dr. Allen Thomson, who passed from the simpler to the more complex forms. Probably the simplest nervous mechanism we can conceive consists of a cell and two fibres. In this diagram, you have a large cell, and attached to this cell you have a fibre conveying an impulse inwards. This fibre I have coloured red, and the direction of the impulse is indicated by an arrow. When the influence reaches this cell. a change occurs in it,

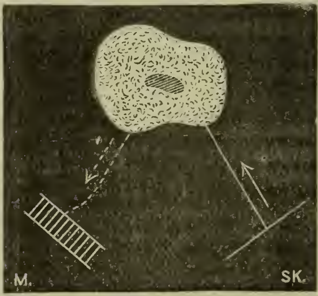

Fig. 7.—Diagram showing simple reflex arrangement. M, muscle; SK, skin.

which results in the transmission along the other fibre of an impression outwards, and when this impression reaches a muscle it excites a contraction. This is an automatic arrangement, and is usually termed a *reflex action.* Touch the skin of an animal of a very humble form, and immediately you have a contraction. To aid the mind in understanding the mechanism, examine the diagram again. The impulse travels along the red fibre (from S K), and comes out at a blue fibre (towards M). The red is the sensory nerve carrying impressions inwards, and the blue one is a motor nerve carrying impressions outwards. The term reflex was first given to an automatic nervous action by Dr. Marshall Hall, but I think it is a very unfortunate one. Reflex, of course, gives one the idea of something reflected —some kind of influence passing into a centre, and then thrown out from the centre, just as a ray of light striking upon a surface would be reflected from that surface. I do not think that is the kind of action. Instead of having it arranged as in that diagram, you may imagine, for instance, the cell to be placed in the length of the nerve fibre. You may have a fibre, for example, as represented in this drawing, and a cell in the centre of the fibre. When you irritate the one end of the fibre, the impression would travel along to the cell, through the cell, and along the fibre again. This cell might have had three processes instead of two, and in that case the cell would distribute the influence which it received from the first fibre. Suppose, for example, the cell (fig. 7) had another fibre passing upwards. The impulse coming in at the red or sensory fibre might then be partly sent to the muscle along the motor fibre, or sent away upwards to another cell, perhaps in the brain. Nerve cells, then, may be regarded as arrangements for generating or for reinforcing the nerve current. Suppose I take this galvanic cell and charge it with acid, and then carry the electric current along wires to an electrical engine, so as to make it work. If I place another cell in the circuit somewhere, this second cell will strengthen the current, and the engine will of course work faster.

Now, in the case of a nervous mechanism, the change which would take place in cell *a* when the end of the fibre passing to it was irritated might be transmitted to cell *b*, which would reinforce the effect, so that you would produce a much greater effect by such a mechanism of two or more cells than by one only. Thus a simple reflex mechanism may become much more complex. For instance, we may have several fibres, instead of one fibre, passing to the cell; or, instead of one cell, we may have half-a-dozen cells all grouped together and connected with various fibres. Thus we would have what we might call a *complex reflex mechanism.* Again, on tracing the development in the higher forms of life, we find that there is a tendency to what may be called a grouping of reflex centres. In the humbler forms of animal life, we have probably reflex centres here and there throughout the organism, but by-and-by you have them clustered together into masses. That is very well seen in the nervous system of an insect. In it you have certain larger masses; one, for instance, in the head, which is essentially connected with the organs of sense. Again, in the thorax and abdomen, we find other groups of reflex centres massed together so as to form ganglia. This tendency to aggregation becomes more and more marked as we ascend in the scale of animal life, until we find its highest development in the cerebro-spinal system of man.

The *spinal cord* is to be regarded in two aspects: as a conductor, and as a reflex centre. In the first place, the outer part of it consists of nerve fibres. The anterior part consists of fibres which carry impressions downwards from the brain to the muscles. The posterior part consists of fibres which carry impressions upwards from the periphery of the body to the brain, or to the grey matter of the cord itself. You see in the transverse section, in the lower part of this diagram, the grey matter in the centre of the cord, which contains numerous nerve cells. This grey matter in the centre of the cord may be regarded as consisting of numerous reflex centres—centres connected with various movements of the limbs and of other parts of the body. Reflex movements are not usually associated with consciousness; they are merely automatic. The molecular change, or whatever it may be, which occurs in the nerve cell never reaches that state of activity which results in consciousness or sensation.

In studying reflex mechanism in animals and also in man we sometimes observe that there is what we may call a diffusion of reflex movements; that is to say, if you set up an irritation in a lower reflex centre, this irritation may pass to other centres, and consequently give rise to more general diffuse movements.

This may be illustrated by reference to the diagram, fig. 9, p. 29. Here we have a lower reflex centre (1), say in the spinal cord, connected by two nerves with muscle M and skin SK. On irritating the skin, the influence may affect only one muscle or group of muscles, or it may be partly diffused or transmitted to a higher centre (2), so as to call into action other groups of muscles. Still higher centres may also be involved, so that the contraction of many muscles may be the result of an irritation applied to the skin.

I may be allowed here to refer to a practical question with regard to reflex movements. I have noticed recently in our newspapers that a discussion has taken place in regard to a very important subject, and one which is somewhat disagreeable in its details—the modes which we adopt of killing animals. I have noticed that it has been objected to one of these modes that violent convulsive movements took place, when, after the animal had been felled, a cane was thrust into the spinal marrow; and in some of the letters it has been assumed that these movements implied consciousness—that is to say, that the creature was actually conscious of pain at the time it made these movements. In the particular method I refer to, after the animal is knocked down with one blow, a rod or cane is pushed into the medulla and the spinal cord. That, of course, is done with the view of completely destroying the animal's power of feeling pain, although I believe consciousness will be entirely abolished by the blow alone. But that is precisely the kind of procedure that would create the violent convulsive movements which have been referred to. If you pass a rod or wire into the spinal cord of the animal which has been killed, you will excite violent spasms. But these spasms are no indication of consciousness; they are simply the result of intense discharges of nerve-energy from the irritated cord, violently excited by the passing of the wire or other substance into the interior of the spinal canal. In connection with the matter, let me remark, that everything possible should be done to prevent pain in the killing of animals. What physicians and surgeons and physiologists have to fight against is pain of every kind, whether occurring in man or in any living creature however humble. Therefore we should direct our thoughts carefully and attentively to devise those methods which may be best suited for suddenly depriving the creature of life, if we hold that we are warranted in depriving it of life to meet our necessities.

To return to our proper subject, let me now direct your attention to a higher stage in the scale of nervous action, and to study what is known of sensation. All the arrangements I have up to this time described may be quite unassociated with sensation, and usually are so. They may occur, of course, along with sensation, but sensation is not necessarily involved. Let me explain this by taking an example. Suppose you see a child sound asleep. In profound sleep, the person is in a state of absolute unconsciousness. Imagine that he is in such an unconscious state; that there are even no dreams. If you tickle the sole of the foot or touch it, the foot is drawn away, the body may be turned over, and numerous movements may occur. These are reflex movements, unassociated with consciousness. Suppose you tickle the sole of the foot of a man who has met with an injury to his spine, which deprives him of the power of voluntary movement, and that even then some movements occur, these movements are, in the circumstances, beyond the control of the person to resist them. He does not *feel* that you touched the sole of his foot, and still the movements occur. We know, from what I have said before, that these movements depend on reflex centres in the spinal cord. But now, go a step higher, and we come to certain centres which are connected with sensation—with a feeling which may be of pleasure or of pain. I must here define what I mean by a sensation, because I find in many books—more especially in some popular books—that the term is used in an exceedingly loose way. Some writers, for instance, in speaking of the action of a reflex centre, which I have just been describing, would use the term in this way :—A sensory nerve carries an impression to the centre; in the centre a *sensation* occurs—and the result is something transmitted along the motor nerve, causing motion. To apply the term sensation to such a change in a nerve centre is not correct. A sensation must be associated with a conscious state, or rather, it is a conscious state; we can have no sensation unless we are, as it were, conscious of the sensation. It is the *consciousness of an impression:* it is a conscious condition, resulting from some kind of irritation applied to the periphery of the body, and of some subsequent changes occurring in the brain. But what is the mechanism of a sensation? What arrangements in the body are necessary for it? They appear to be three in number. *First*, we must have what we call a terminal apparatus for receiving an external stimulus; *second*, we must have a nerve for conveying the change thus produced; and *third*, we must have a sentient brain to receive the message. We can illustrate this by what occurs in the process by which we become conscious of light. Light outside of us may be regarded as a movement, just as sound is a movement, and when it acts on the retina of the eye, it excites there some kind of activity; this activity irritates the extremities of the optic nerve; the impression is carried to the brain, and we become conscious of the impression. That is a sensation of light. Imagine a person sound asleep. Gently open the eye and put a light before it. The nervous apparatus will then act, no doubt, but the effect on the brain is not perceived. Whatever change may occur in the brain in these circumstances, it really does not rise to the condition of what we may call a luminous impression. Thus, even with a light before the eye, the sleeping person does not *see.* The same is true with regard to all the other senses.

Each sense has its own terminal organ, and that terminal organ is specially fitted for the reception of a particular kind of external stimulus. By means of our senses we thus derive information regarding the external world. Outside of us there are various movements—the movements of sound, the movements of light, molecular movements, and those delicate movements which result in what we call chemical change.

We have terminal organs specially fitted for the reception of most of these movements. When the nervous apparatus works, these movements become transformed in our consciousness into sensations. For example, the retina is a structure no doubt specially arranged for being acted upon by light. Some recent interesting observations by Boll and Kühne have shown that the action of light upon it is something very analogous to what happens when light acts upon a sensitive photographic plate. Again, in the case of sound, we have in the ear a special terminal apparatus for vibrations of sound. Thus the movements ultimately irritate the auditory nerve, and the impression is a sensation of sound. The necessity of a terminal apparatus does not seem at first very evident. You say, Why should not the external energy, or whatever it is, act directly on the end of the nerve? but physiology has shown us that it does *not* affect the nerve at all. A terminal organ seems to be absolutely necessary. Thus, there is on the retina of the eye a spot which is not sensitive to light. It has been long known as the blind spot. It is the part where the fibres of the optic nerve are bare—that is, where there is no proper retinal structure. Consequently, the fibres of the optic nerve, to be excited by light, must be excited through the terminal organ. The same is no doubt true of the other senses. These nerves which carry impressions of light, of sound, of taste, of touch, are usually termed nerves of *special* sensibility; and the reason is, that in whatever way you irritate one of these nerves of special sensibility, you always produce the same kind of effect. Thus, when you irritate the optic nerve by pressure, by an electric current, by light on the retina, or chemically, or by cutting it, the effect *is always a luminous impression.* That depends upon the principle I have already laid down: the result is owing to what we have at the end of the nerve. The message goes along the optic nerve, and when it reaches the brain, it there excites changes which are always interpreted by the mind as a luminous impression.

Up to this point, you can imagine an animal sentient; that is to say, conscious of certain sensations of light, of sound, or of some of its wants, and conscious also of what you might call feelings of the body — impressions transmitted from various organs, which give rise to a sense of satisfaction or of the reverse. This animal might also be capable of moving, it might have an electrical organ, or it might have secretory organs, but still there might be nothing of the nature of an emotion, except it might be a feeling of pain or of pleasure. But such a creature might have no ideas or thoughts, or power of restraint or of volition. Therefore, as we rise higher in the scale, we come to a still more complex nervous arrangement, namely, one for regulating the other centres. One of the most interesting steps in modern physiology has been, I think, the discovery that certain nerves, instead of stimulating to contraction, have the reverse effect; that is to say, they stop contraction. This was first discovered in the case of the heart by Weber, a German physiologist. It was well known that the heart of some animals, say the frog, will pulsate for a considerable time after it has been removed from the body, and that these pulsations go on in consequence of the heart having little nerve centres of its own. The heart of the frog and of the higher animals, however, is supplied by two great nerves, which connect these intrinsic centres with the cerebro-spinal system. Both of these nerves come from the medulla, the upper part of the spinal cord. Weber's discovery was this—if you irritate in the neck the great nerve called the pneumogastric or vagus, the heart beats more slowly, or it may stop its contractions. Fibres of this nerve find their way to the heart. Now, observe that you have not caused a spasmodic contraction on stimulating the nerve, but the very reverse. If the nerve be cut, and the lower part irritated very gently, the heart will move more slowly; remove the irritation and it will go on as before. The heart is thus under two nervous influences. One goes along the pneumogastric, causing it to go slowly; the other along the sympathetic, causing it to go faster. The heart is spurred on by the one and restrained by the other. It has recently been shown, moreover, that in the heart itself we have a centre which also restrains its activity. Such nerves or nerve centres as restrain the activity of other nerves or of other nerve centres, are called *inhibitory*.

In the accompanying figure (fig. 8), showing the nervous mechanism of the heart, the ganglion connected with the sympathetic is marked A, that in connection with the pneumogastric (inhibitory) I, and the third, controlled by the other two, R.

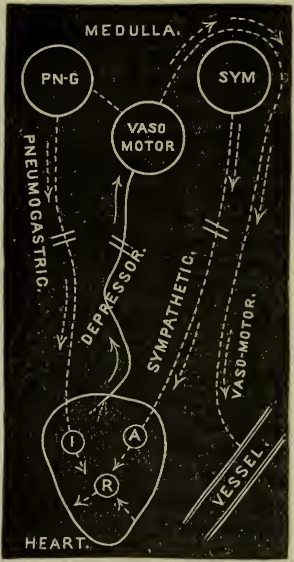

Fig. 8.—Diagram showing Arrangement of the Heart and Vessels. I, Inhibitory centre; A, accelerating centre connected with sympathetic through spinal cord; R, reflex centre.

Regarding the mechanism of inhibition we know nothing definite. It is possible that the effect may be the result of throwing in some kind of resistance at the reflex centre, so as to prevent it working quickly, or perhaps the nervous arrangements are such that there may be some kind of short circuiting of the nervous currents; in other words, a mechanism by which it is possible to carry away the ordinary current which keeps up the activity of the heart. Such an arrangement of sending the current along another channel would prevent the heart from working, and cause it to stop. There are many other examples of inhibition, some of a most interesting character. I may be allowed to refer to one other, which will show the wonderful influence which the nervous system has upon all our functions. I show you an apparatus which is intended to illustrate some facts regarding the circulation of the blood. It consists of two glass cylinders, placed vertically, and communicating with each other by a horizontal glass tube. Let the one vertical tube represent the arterial system and the other the venous, and let the horizontal tube represent the system of capillaries which connects the end of the arteries with the commencement of the veins. Suppose now that by means of this syringe or pump, which may regarded as the heart, I force water into the arterial system; you will observe that the pressure is at once increased in this system, so as to be greater than in the venous system, but that the two soon become equal by the fluid in the arterial system emptying itself into the venous. This is exactly what is the state of matters in the living body. When the heart contracts, it throws blood into the arterial system, and consequently the pressure is much greater in the arteries than in the veins. The arteries, however, empty themselves into the veins through the capillaries; and if the heart did not again contract, the pressure in the arterial and venous systems would be equalised, and the circulation would stop. In some circumstances, the arterial circulation may be such that the heart must overcome a great resistance in forcing the fluid onwards. Suppose, for instance, you had a contractile structure, or pump, forcing the water through the streets of a town, and that from some cause or other the pipes became very much contracted in some parts of the town, so as to offer great resistance to the force of the pump; the resistance might become so great that the pump would be unable to drive the fluid onwards, and the pump itself might, in its attempts to overcome the resistance, be permanently injured. What naturally would suggest itself to the mind of an engineer? He would remove the resistance by widening the pipes at the contracted portion. We have somewhat analogous arrangements in the body. The blood-vessels are under the control of a system of nerve filaments in the sympathetic, termed *vaso-motor*, by the action of which on their muscular walls the calibre of the vessels is regulated. These *vaso-motor* fibres originate in the *medulla oblongata* at the base of the brain, from a spot termed the *vaso-motor centre.* It has recently been shown that the action of this centre may be inhibited (or partially thrown out of gear, as it were), by the action of a set of filaments in the pneumogastric, which carry impressions upwards from the heart to the brain. These filaments, in some animals, form a slender nerve, distinct from the pneumogastric below a certain point, now called the *depressor* nerve (see fig. 8). The action of this nerve is probably as follows: Suppose, for example, that the smaller arteries throughout the body were in a state of such contraction that the blood could not pass quickly through them. In these circumstances, the large vessels would become distended, the tension of the blood on their walls increased, and the heart would have to labour hard to force the blood onwards. When this condition occurs, an influence may be sent from the heart, along the *depressor* nerve, to the *vaso-motor* centre in the medulla, the effect of which is to inhibit this centre. The instant the centre is inhibited the smaller blood-vessels relax, the blood flows more freely through them, the tension or pressure in the larger vessels is diminished, and the heart, having less resistance in front, works more easily. Thus we must regard the blood-vessels as a system of living tubes, subject to such influences of the nervous system as the requirements of the tissues and of the heart demand.

Many other examples of inhibition might be given. There may be unconscious or conscious inhibition. The inhibition acting on the heart, for instance, is unassociated with consciousness. We are not conscious of any such mechanism as I have just described. But in rare circumstances, I believe, we may be conscious of it. There was a physiologist in Germany, named Czermak, who died some years ago, and who could compress the pneumogastric in his neck. He noticed that when he did so the heart beat more slowly, and he had a feeling of intense constriction in the region of the heart. He said it was precisely the same kind of feeling of constriction which we sometimes experience along with a great grief, and this may explain to us how it is that emotional states of our higher centres, acting downwards, may influence the heart directly. So that the popular notion of emotional states acting directly on the heart is physiologically true.

Another step in the development of the nervous system is the setting aside of centres having functions necessary for life, such as to carry on the mechanism of respiration and the process of swallowing. These great centres are situated in the medulla oblongata. You will see them represented in the following diagram. Some of the nerves connected with these centres are distributed to the lungs, some to the heart and vessels, and some to the digestive organs. All these arrangements are for the purpose of effecting reflex movements, of which we may or may not be conscious, but which we cannot restrain. Thus we cannot restrain breathing for almost any time; the desire to breathe becomes unconquerable. So with regard to the calibre of vessels, and consequently the distribution of blood; and also with regard to swallowing, and the movements of the digestive organs. The *medulla oblongata* is often spoken of by French physiologists as a *vital* part, the *nœud vital.* They imagined that at this point life existed more than at any other part of the body. That is not the true way to put it. If we destroy this part of the nervous system we destroy life, in consequence of these great functions necessary to life being at once stopped, but vitality is not greater at that part than at any other.

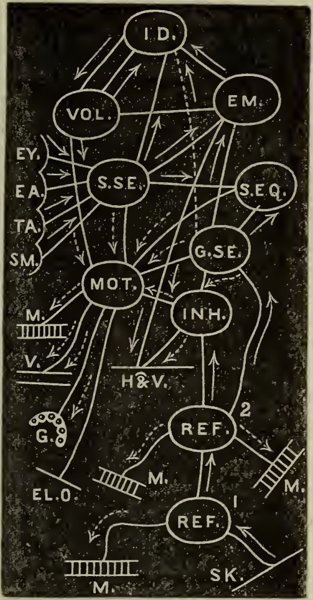

Fig. 9.—Diagram showing various kinds of Nervous Actions. M, muscle; SK, skin; REF, reflex centre; INH, inhibitory centre; MOT, motor centre; G.SE, centre of general sensation; S.SE, centre of special sensation; S.EQ, sense of equilibrium; VOL, volitional centre; EM, emotional centre; ID, ideational centre; EY, eye; EA, ear; TA, taste; SM, smell; V, vessel; G, gland; H&V, heart and vessels. The arrows indicate the direction of the currents. By following the directions indicated by the arrows, the influence of one centre over another may be studied.

The exact position of the centres indicated in the diagram, fig. 9, may be seen in fig. 10.

We have now supposed these centres added to other centres, until the mechanism becomes very complex. Imagine, further, that a creature has many muscles for moving different organs, and that these muscles are more or less connected together by reflex centres. You will see at once the necessity for what we may call the *co-ordinating system.* This co-ordinating system exists in the lower brain or cerebellum marked with the letters CO (fig. 10). Let me explain what I mean by co-ordinating. For instance, if I lift this match-box by finger and thumb, and flex my arm, I have caused a number of muscles to contract more or less. These contractions have had to be precisely regulated with regard to each other so as to produce this definite effect, but I do all this unconsciously. Influences are sent out along many nerves to these different muscles, and the result is a co-ordinating movement. This co-ordination of movement is carried on to a much larger extent, of course, in playing or using a difficult instrument, as in the movements of the hand of a performer on a piano. The movements of the muscles require to be co-ordinated. This is accomplished principally by the agency of the *cerebellum.* Many facts could be brought before you in support of this view, but one of the most important, perhaps, is that which you can see illustrated in this diagram, fig. 11. Suppose this represents a pigeon, from which the cerebellum has been removed. There is no loss of consciousness. It is able to

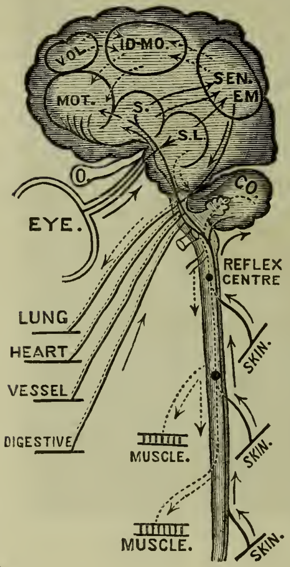

Fig. 10. — Diagram of Cerebro-Spinal Axis, showing position of various centres. CO, co-ordinating; SL, sense of light; S, sensory; MOT, motor; SEN, sensory; EM, emotional; VOL, volitional; ID-MO, ideo-motor; arrows indicate direction of current.

take its food; all its senses are intact; but it is unable to fly and unable to walk—not because it is paralysed, but because it is incapable of *regulating* its movements in a definite way. When it attempts to flap both wings, it may move one wing inwards and the other outwards; it does not co-ordinate the movements, so as to produce the desired effect.

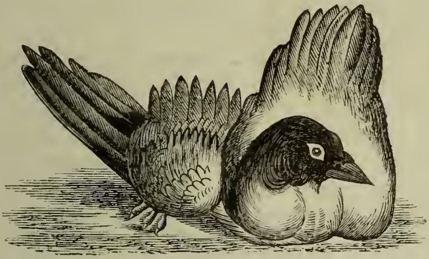

Fig. 11.—PIGEON, in which the Cerebellum has been injured or removed.

We pass upwards to the higher centres in the brain, and finally to the brain itself. There are the *corpora striata,* specially connected with movement, any injury to which will cause loss of movement on the opposite side of the body. The reason why the effect is on the opposite side is illustrated by Dr. Allen Thomson, as you see in the diagram, where you observe the motor fibres crossing at the top of the cord. The *optic thalami* are not connected with the sense of vision, as was at one time supposed, but are centres for receiving sensory impressions passing upwards. These sensory impressions may pass beyond these into cerebral centres, where I believe consciousness actually occurs. Behind the optic thalami we have the *optic lobes,** which receive the fibres of the optic nerves. The optic lobes act as reflex centres connected with sight. In illustration of this, I might take a phenomenon which may sometimes be seen in a person in a somnambulistic state. In this condition, the eyes of the person may be fully open, but he is quite unconscious or is wrapped up in his own dream. If, in these circumstances, a light is brought before the eye, the person does not push his head against the light. He avoids the light. He moves to one side, as if he were actually conscious of the movement. The stimulation by light seems to excite a movement unconsciously, and a movement is therefore made to avoid the light. Here the optic lobes probably act simply as automatic reflex centres.

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* The parts termed optic lobes are in the higher forms of brain subdivided still further; each lobe is divided into two, and the *four* bodies thus formed have been called *corpora quadrigemina.*

The *cerebral hemispheres* consist of a layer of grey matter over white matter in the centre. The grey matter is raised in convolutions.

Flourens and the older observers were aware of the fact, that as successive slices of grey matter were removed from the surface of the cerebrum, an animal becomes more and more dull and stupid, until at last all indications of perception and volition disappear. A pigeon in this condition, as depicted in fig. 12, if carefully fed, may live for many months. The following description, given by Dalton, is so accurate as to merit quotation:—"The effect of this mutilation is simply to plunge the animal into a state of profound stupor, in which it is almost entirely inattentive to surrounding objects. The bird remains sitting motionless upon his perch, or standing upon the ground, with the eyes closed, and the head sunk upon the shoulders. The plumage is smooth and glossy, but is uniformly expanded by a kind of erection of the feathers, so that the body appears somewhat

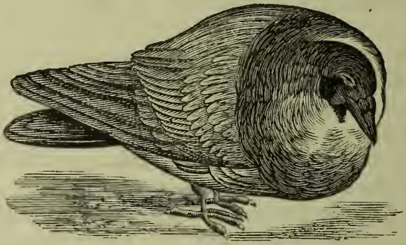

Fig. 12.—PIGEON, in which the Cerebrum has been injured or removed.

puffed out and larger than usual. Occasionally the bird opens its eyes with a vacant stare, stretches its neck, perhaps shakes its bill once or twice, or smoothes down the feathers upon its shoulders, and then relapses into its former apathetic condition." Similar observations have also been made on reptiles and mammals, but the latter survive the operation for a comparatively short time. In watching such an animal, it is difficult to divest one's mind of the idea that it still feels, and hears, and sees. It may be observed, however, that it makes no movement unless stimulated from without. Thus, it may remain motionless for many hours; but, if pushed, or even gently touched, it will then move. It manifests no fear even when placed in circumstances likely to excite it, and it will walk over the edge of a table, or into the fire, quite regardless of consequences. There is thus no proof that it experiences any sensation in the sense of consciousness of impressions; or, in other words, there is no perception. As well remarked by Michael Foster: "No image, whether pleasant or terrible, whether of food or of an enemy, produces any effect on it, other than that of an object reflecting more or less light. And, though the plaintive character of the cry which it gives forth when pinched, suggests to the observer the existence of passion, it is probable that this is a wrong interpretation of a vocal action; the cry appears plaintive, simply because, in consquence of the completeness of the reflex nervous machinery, and the absence of the usual restraints, it is prolonged. The animal is able to execute all its ordinary bodily movements, but in its performances nothing is ever seen to indicate the retention of an educated intelligence."

The method of removing a portion of the brain is open to many objections, the chief of which is, that the severity of the operation and the loss of blood may cause such a state of shock, as to vitiate any inferences that might be drawn from the facts recorded. A new method, however, has been devised, namely, that of stimulating the nervous centres by electricity, and observing the results.

It was supposed by the older physiologists, that the whole of this great mass of brain matter was connected with what we may term *mental phenomena,* and had nothing to do with motor phenomena. But recently some observations have been made which would appear to indicate that certain parts of the grey matter on the surface of the brain are connected with motion. During the Franco-Prussian war, a French soldier had the misfortune to have a portion of brain exposed, and two German surgeons, Fritsch and Hitzig, had occasion to stimulate the surface of the brain feebly with an electric current. It was supposed, up to this time, that the surface of the brain was quite insensitive to a current of electricity, but these surgeons observed a movement of the eyeballs. That was the beginning of an important research carried on by Fritsch and Hitzig in Germany, and by Dr. Ferrier in London, which has given us a vast number of facts regarding the functions of the grey matter over the central region of the brain. If the grey matter in the central region of the brain be irritated at certain points with a feeble current of electricity, the result is a definite movement of some part of the body. For instance, Dr. Ferrier found that when he touched a particular part, the right fore-limb was extended; when he touched another part, the left fore-limb; another part, the right hind-foot, and so on, as if there were a number of centres definitely arranged for these movements. Dr. Ferrier called these centres *idio-motor centres*, supposing that they had probably to do with what we may call an idea which results in a movement. I am inclined to think that many of the movements observed by these physiologists are really of a reflex character, that is to say, when you irritate an area of grey matter on the surface of the brain, impressions are carried down to a motor centre, perhaps in the corpus striatum. That is a matter, however, upon which I have not time to dilate. If you irritate the anterior part of the brain, as has been pointed out by various physiologists, you tend to restrain reflex movements, which have their centres in the spinal cord. I am quite sure, from my own observation, that that is the case. If you irritate this part of the brain, some reflex movements may be restrained or interrupted. Thus the anterior part of the cerebral convolutions may be supposed to contain inhibitory centres, which may act either on the motor centres in the middle region of the brain, or on the motor centres in the cord. The back part of the brain is, I believe, principally for sensation. I have put in here also in the diagram, fig. 10, the emotional centres. Some have imagined that emotional impressions may result from activity in the ganglia at the base of the brain. I think the evidence in support of that statement is very insufficient.

Such, then, is what I may call the general mechanism of the nervous system. You will understand it better, perhaps, by referring again to the diagram (fig. 9), in which the arrows represent the direction of the nervous currents. Here first are the lower reflex centres (1 and 2). These may act upon the higher reflex centres. If an influence travel up to a higher centre we have a general sensation. This sensation, which may occur in an animal low in the scale, may act on motor centres, and these motor centres may cause muscles to work. I have introduced here an inhibitory centre, which might restrain the activity of the motor centre. Then we have the emotional centre, which might receive influences from a centre of special sensation, or from a centre of general sensation. Highest of all, we have the volitional centres and ideational centres.

I have now got to the end of my subject. I should like to show one experiment which may illustrate to you what might possibly be the kind of action which takes place in some nervous arrangements. It is very remarkable that a very feeble stimulus originated in the brain, is quite sufficient to produce very powerful spasmodic effects. A man wills to perform certain movements, and instantly you have a number of muscles acting together. You can scarcely imagine that energy exciting all these movements really originates in a particular part of the brain, and is the same energy which carries it to a termination. I have often thought it not at all improbable, that in nervous mechanisms, we may have something of the nature of what a practical electrician would term a system of relays. That is to say, you can have a feeble current of electricity—rendered feeble by passing along a distance—too weak to work a machine, but quite sufficient to close a local circuit, getting new force from local cells, and thus carrying the current onwards. If that arrangement does not exist in the nervous system, then another method might be adopted. The same current might be sent alternately in different directions, and caused to do different kinds of work. That I have spoken of already. Here I have fitted up an experiment which suggests, as it were, what I mean. I have here a current of electricity passing into an arrangement by which I can send it to work an electro-magnetic engine, or to work two tuning-forks, or to cause a telephone to sound loudly, and, if the current were strong enough, it might produce light. That experiment shows how one may have many different effects produced by one current.

The last point I wish to refer to is with regard to the question of the connection between mental phenomena generally and activity of brain. On the one side we have undoubtedly the fact of the dependence of mental phenomena on brain. That is generally admitted. Assuming that this is the case, we know that if we interfere in any way with the brain, we interfere with the mental state of the person. This is illustrated by the very well-known and sad facts of insanity. At one time insanity was supposed to be a diseased mental state. In one sense it is; but we know perfectly well that it is also a bodily disease; and I would take this opportunity, as I have often done before, of pressing this aspect of the subject upon the public. It is now generally admitted by all well-informed persons, although there still lingers a superstitious notion that insanity is something different from a bodily affection. When this view held ground—that insanity was merely a mental state, not connected with the body—it led, as many of you know, to very wrong systems of treatment of the unfortunate insane. But when men found out that there can be no form of insanity without some kind of disorganization—some morbid change or other in the grey matter of the surface of the brain—then there was a guide to the treatment of such cases, in the direction likely to cure the sufferer.

For instance, we at one time supposed that nothing morbid was discovered in the brain of the insane; but histological examination has shown us that traces of some change or other are always to be found. The whole of this subject is by no means worked out. It is indeed still in its very infancy;

but we have quite enough evidence to go upon to satisfy us that in insanity we have to deal with a bodily disease; and consequently all the efforts of humane physicians engaged in the treatment of the insane are directed towards placing them in as favourable a condition as they possibly can be for recovery. They treat them upon the same general principles as they would attempt to treat disease in any other organ of the body.

Another proof of the fact that mental phenomena depend on the brain, is found in what we notice with regard to nutrition. If we interfere in any way with the quality of the blood going to the brain, the effect is apparent. We know, for instance, that the introduction of alcohol into the blood produces a most marked change. If you can imagine a person under the influence of alcohol, in a state of intoxication, and that condition to be permanent, you would justly regard that person as in an insane state; that is to say, the activities of the brain are altered by the introduction of this matter into the system. The reason why I allude to this is to show how intimately mental states depend upon states of blood and brain. We must all think of mental states as depending mainly upon brain and on blood—the kind and quality of blood, and the arrangement for getting rid of the waste products of the brain, so as to facilitate those chemical changes which result in brain activity. On the other hand, we have many phenomena connected with mental activity which at present have no physiological explanation. Such are the phenomena of the emotional states, and the facts of memory and of intellectual action. We simply know that these states are connected with a particular part of the brain, but we have no knowledge whatever of the changes which result in the part of the brain connected with these states. The mechanism is quite unknown; and I believe myself it is very likely that it may be for ever hidden. It is impossible to bridge across what may be regarded as the gulf between the *objective*—the chemical and physical operations occurring in the grey matter of the brain — and the *subjective,* or mental states which we associate with these. We cannot really think of the one, as it were, passing into the other. The mind fails in attempting to grasp the connection between the two. Suppose, for example, that in the future this may be the case—that we had examined every bit of the surface of the brain, and knew precisely where every nerve cell was placed, and how these various nerve cells were connected together; suppose we knew all the chemical changes occurring in this part of the brain, and how the impulse went from nerve cell to nerve cell: would we be any nearer an understanding of how these actions produced particular mental conditions? I do not see that we could possibly be any nearer. We would simply be able to say that mental conditions were associated with such and such occurrences and such and such chemical phenomena. It has always appeared to me that it was useless to require of physiologists an explanation of the relation between mind and matter. They cannot give it. It is one of the "ultimate truths" of their science. Nor need it be imagined that this is the *only* insoluble problem of physiological science. For example, the beginning of life is just as mysterious as its close. When we examine an ovum or egg—a minute microscopic particle of living matter—who can explain by what molecular arrangement it is that it contains all the potentiality of a future being? And if you go to the department of physical or chemical science, you will meet with the same difficulties. There are ultimate problems in physical and chemical science which are really just as obscure in many ways as what we may call the ultimate problems of physiology. I have often thought that the workings of the brain and other so-called vital phenomena are connected with the very highest problems of chemistry and of physics. Further, we are very far from having explored its minute anatomy. We know absolutely nothing of the chemical changes occurring in the brain—and chemical changes are constantly occurring there—the co-incident phenomena of which are our states of mental activity. There have been many opinions formed by thinkers as to the connection between mind and brain. Some have supposed the brain to be like an instrument performed upon by some invisible agency; others have conjectured that you have the two things—brain action and mind action—going on and working side by side.

I think by far the safest view to take of the subject is to put it in this way: In our present phase of existence there is a most intimate connection between mental phenomena and physical states of the brain. You cannot have mental phenomena, in our present state of existence, without some operations occurring in these higher centres which I have been speaking about. That is a totally different thing, however, from saying that these mental states are simply the product of these physical operations, and that when these physical operations cease the mental states cease also.

In this particular region we pass from the domain of science into the domain of belief, dependant upon another kind of evidence. I think that that is the only legitimate way of meeting the great difficulty. We pass from the field of science—from what we know or from what we infer from certain facts—into what I might call the field of hope and faith; not faith simply as blind acceptance of what we are told, but a faith associated with hope, which is as real as if we had a demonstration of facts.

Apart from these speculations, which will probably be repeated in diverse forms by man to the end of time, there are certain practical aspects of this subject which I have brought under your notice to-night. First of all, we have the general fact that mental states are affected by physiological conditions. We have our physiological conditions more or less under our own control, therefore we have our mental state more or less under our control. In this way, physiologically, every man has the power to make or mar himself. He cannot practise any vice, he cannot indulge habitually in anything that interferes with the nutrition of the brain, without affecting the physical organization of this important part of his body; and when he affects the physical organization of this part, he must inevitably affect his mental qualities. That is what might be called a very materialistic way of putting it, but I think it is true. You cannot possibly affect your nervous organism without leaving certain impressions upon it which will alter you from what you were before.

The study of nervous physiology also indicates, I think, the importance of training, or developing the different parts of the brain. We train muscles by exercise, and so we may train the different organs of the brain by proper exercise also, by intellectual work, by strengthening the power of the will, and by the regulation of our emotions. I think probably the highest of all our mental states, that which above all distinguishes man from the other animals, is what may be called the *power of the will*, or the exhibition of the faculty of restraint. We begin our education really by being taught to restrain ourselves. In the same way, as we go through life we are taught to curb our tempers, and to do our duty even at times when it may be disagreeable to do so. Now there is a physiological basis for this. That is what I want particularly tc enforce. If we have special centres connected with restraint, as I have pointed out, it is quite evident that, by working these centres over and over again, you increase their power, and consequently it becomes easier for a man afterwards to restrain himself than it was at first. So that we go back, with regard to these matters, to the words written many years ago by the wisest of men: "He that ruleth his spirit is better than he that taketh a city." And in Solomon's wisdom the worst that could be said of a man, as indicating failure and desolation, was, that "He that hath not rule over his own spirit, is like a city that is broken down, and without walls."

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